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[54] **GUIDED MISSILE CONTROL SYSTEMS**

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[52] **U.S. Cl.** **244/3.13;** 244/3.19
[51] **Int. Cl.** **F41g 9/00;** F41g 11/00; F41g 7/14
[58] **Field of Search** 244/14, 3.13, 3.14

[56] **References Cited**

UNITED STATES PATENTS

2,801,815 8/1957 Williams 244/14

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EXEMPLARY CLAIM

1. In an antiaircraft system, target tracking means for continuously establishing the position of a target aircraft in space, missile tracking means for similarly establishing the position of a missile, computing means responsive to position information from both said target and missile tracking means to produce control signals for said missile to insure interception of the target thereby and means for substituting the target tracking means for said missile tracking means as a source of missile position information for said computing means during the final phases of an engagement.

7 Claims, 4 Drawing Figures

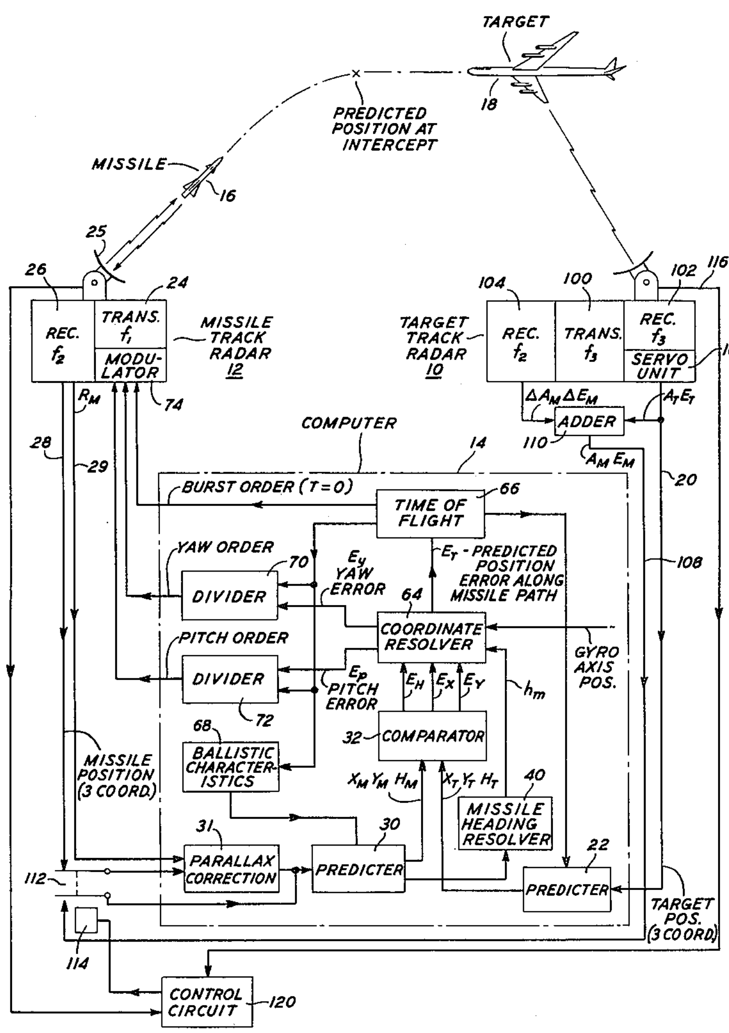

FIG. 1

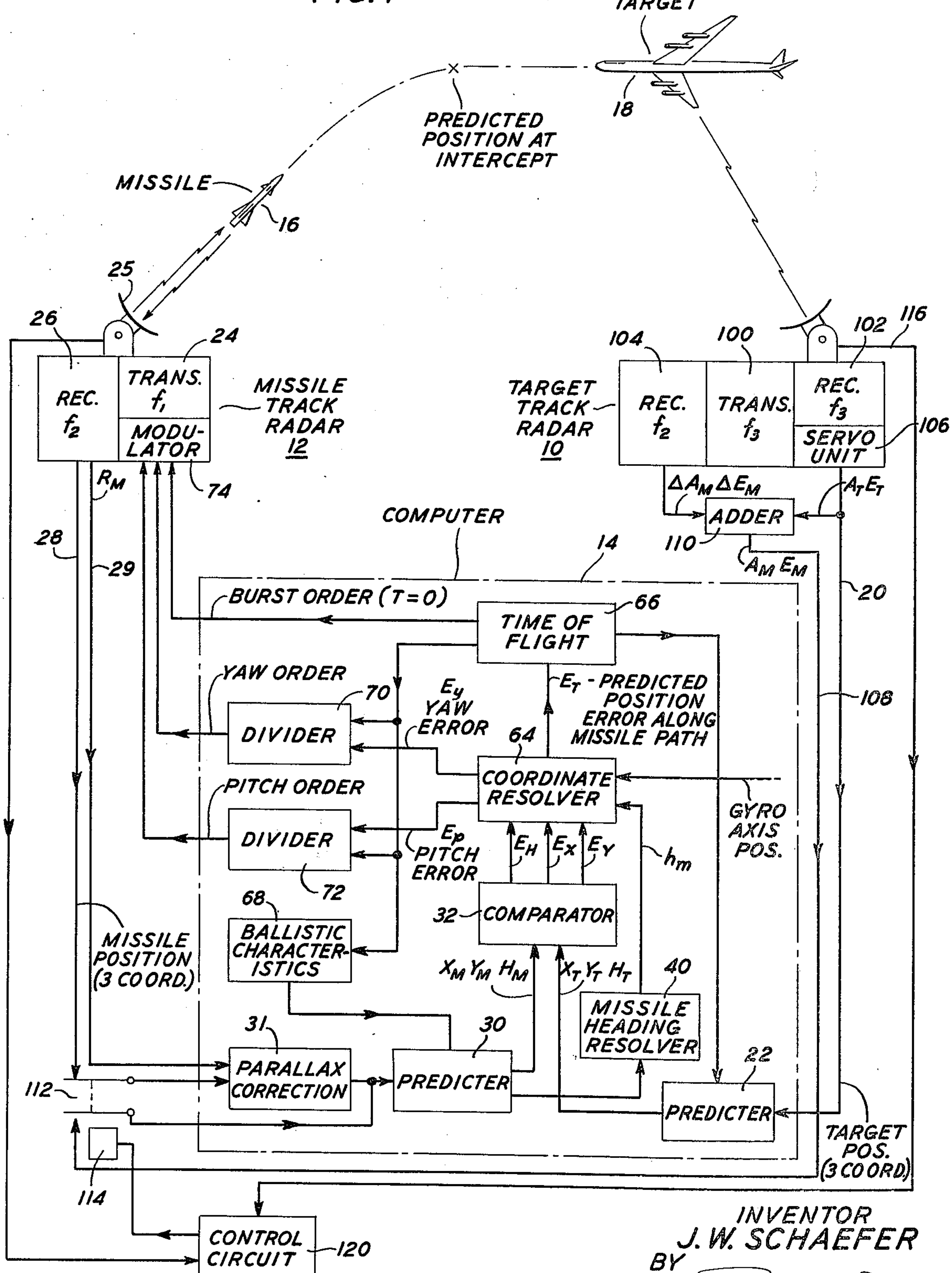

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FIG. 2

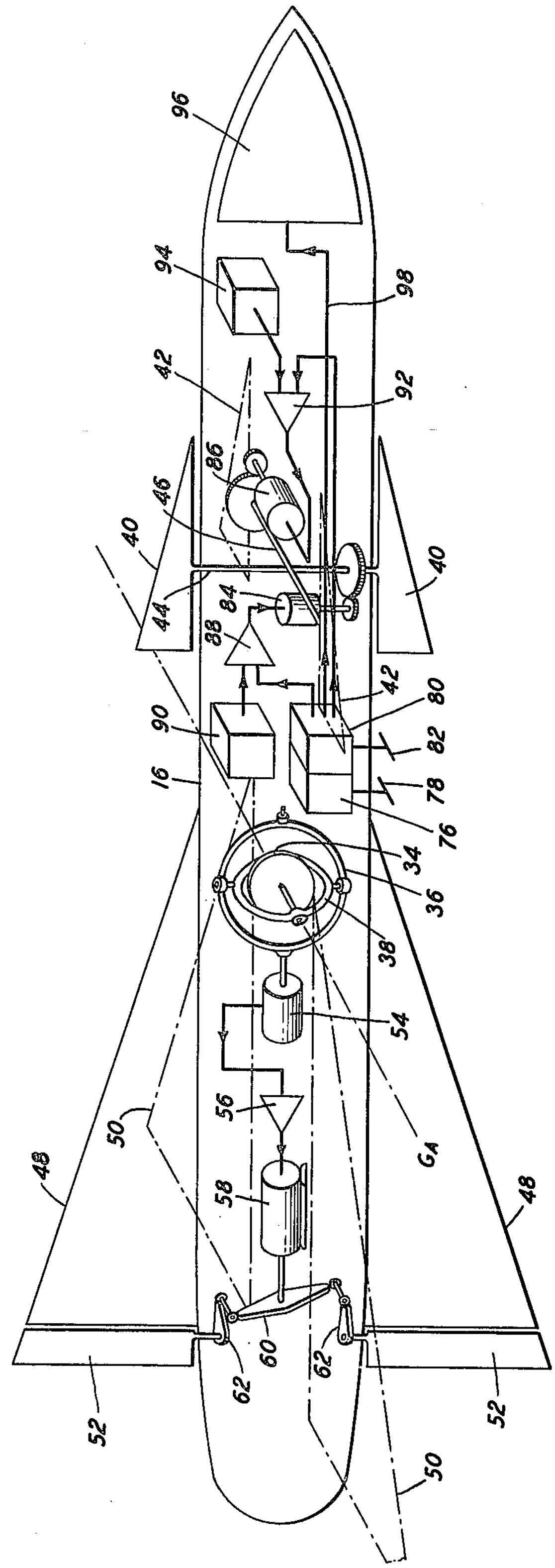

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FIG. 3

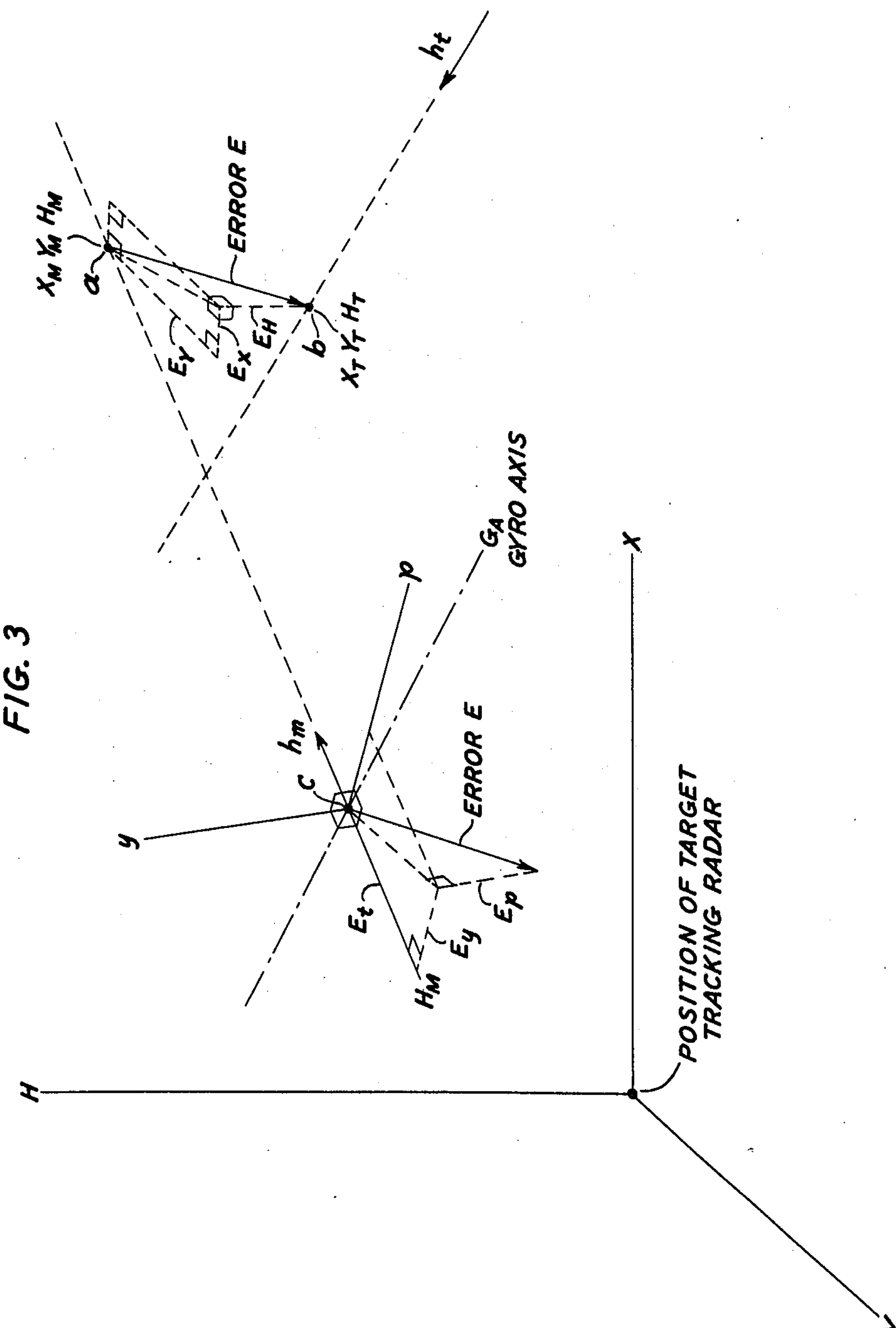

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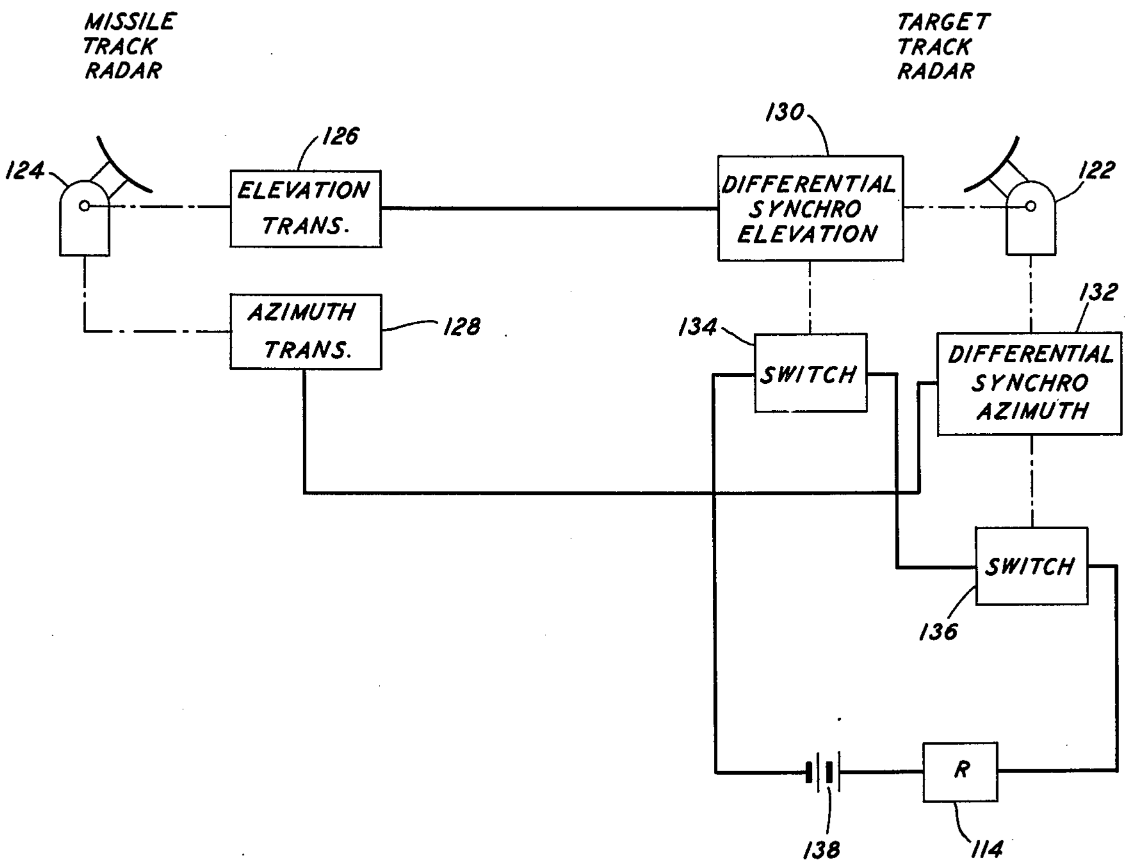
FIG. 4



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GUIDED MISSILE CONTROL SYSTEMS

This invention relates to guided missile systems and more particularly to improvements in those missile systems employing command guidance techniques.

In a copending application, Ser. No. 449,396, filed Aug. 12, 1954 in the names of E. L. Norton and the present inventor and assigned to the assignee of the present application, which matured into U.S. Pat. No. 3,156,435 on Nov. 10, 1964, there was disclosed a guided missile system designed for the interception and destruction of high altitude, high performance bombing aircraft against which adequate defense with conventional antiaircraft artillery is inoperative. The extreme ranges at which engagement must occur to prevent a successful bombing attack make it necessary to provide some means for adjusting the course of a projectile launched against the bomber during the rather considerable time of flight between launching and interception.

As disclosed in the above-mentioned copending application, a practical guided missile system for such applications may include a missile, normally self-propelled, which may be controlled in accordance with commands issued by a ground based guidance equipment. This guidance equipment includes precision radars for individually tracking both the target and the missile launched against the target to obtain data as to the present positions of both. These data are supplied to a computer which predicts the future position of the target at an assumed time of interception and generates orders for transmission to the missile during its flight to control the course thereof in such a way as to insure interception of the target at the assumed time. Equipment aboard the missile provides a frame of reference traveling with the missile and identifiable at the location of the ground guidance equipment with respect to which control orders may be produced.

Although the command guidance system is considered highly efficient there are other systems of missile guidance which have attractive features. One of these which is now well known is the co-called beam riding system of missile guidance. Here a tracking device, usually a ground based radar is employed to track the target continuously and the missile is launched in such a way as to intercept the beam of the radar shortly after launch. Detection devices aboard the missile respond to the beam when intercepted and provide inputs for a missile-borne computer which determines those adjustments in the controls of the missile which are required to maintain the missile in the beam as the beam is swept to follow the flight of the target. This system has the inherent advantage that a single radar or guidance device is employed. In more detail the use of a single radar eliminates the need for precise corrections for parallax between the locations of the two tracking radars of the command system. In addition, since only a single radar is employed bore-sighting errors are not compounded. Normally such matters do not constitute so great a disadvantage as to outweigh the greater advantages of the command system. However, at extreme ranges and during the final phases of an engagement slight resultant misalignments between the two radars may seriously affect performance. On the other hand the beam riding system has the serious disadvantage that the missile does not follow the most efficient course (in terms of time and fuel) to the target.

It is an object of the present invention to so modify a command guidance system as to make available therein the attractive features of the beam riding missile system of guidance without incurring the penalties inherent in the beam riding system.

In accordance with this object the command missile system of the present invention is generally the same as that of the copending application referred to above. In addition to the elements thereof as outlined above, means are provided for determining when the beams of the tracking radars for both missile and target have approached one another to within predetermined limits. At this time, which indicates effective proximity of the missile and the target, means are actuated for transferring the missile tracking function from the missile tracking radar to the target tracking radar. For this purpose modifications are made in the target tracking radar which enable it to receive both return pulses from the target and those from the missile which occur at a different frequency. The switching device referred to above transfers the missile position inputs to the computer from the missile tracking radar to the target tracking radar and thus makes available for the final phases of an attack the advantageous single reference system of guidance normally associated with a beam riding system.

The above and other features of the invention will be described in detail in the following specification taken in connection with the drawings, in which

FIG. **1** is a block schematic diagram of the complete command missile guidance system of the invention;

FIG. **2** is a diagram in schematic form of the missile employed in the system of FIG. **1** showing the equipment required aboard the missile;

FIG. **3** is a vector diagram illustrating the missile command problem and the manner in which the orders for transmission to the missile are computed; and

FIG. **4** is a block diagram of the control system required for transferring the missile tracking function from the missile tracking radar of the target tracking radar and provides details of the control circuit shown schematically in FIG. **1**.

In the broadest sense the antiaircraft guided missile system of the invention comprises a target tracking device **10**, a missile tracking device **12**, a computer **14** and a missile **16**, all as shown in the block diagram of FIG. **1**. Target tracking device **10** which preferably comprises a precision automatic tracking radar is ranged continuously to provide data as to the present position of a target aircraft **18**. This tracking radar may, for example, be similar to the well known SCR-584 radar which is described in detail in "Electronics" for November 1945 beginning at page 104, for December 1945 beginning at page 104 and for February 1946 beginning at page 110. Briefly this radar is an automatic tracking radar employing conical lobing whereby azimuth and elevation error signals are produced by the receiver. These signals may be applied to servo systems to cause the radar antenna to continuously track the target in both elevation and azimuth. In addition this radar includes a range unit also responsive to the reflected radar pulses which automatically maintains itself adjusted to represent the slant range to the target.

As shown in FIG. **1** target tracking radar **10** includes a transmitter **100** operating at a frequency f_3 which is used only by this radar in the present system, a receiver unit **102** tuned to receive echo signals at a frequency

f_3 and a second receiver unit **104** also associated with the same radar antenna and tuned to receive echoes at a frequency f_2 which as will be described below identifies those return signals emanating from the missile. Receiver units **102** and **104** may be identical with the exception of the frequency to which they are tuned and may conveniently be connected to the same radio frequency components of the radar transmit-receive equipment. This can be accomplished at radio frequency through the use of a conventional branching network, the output of which is applied to two preamplifiers each associated with its own mixer, intermediate frequency amplifier, and other necessary receiver circuitry. As will appear below, receiver unit **104** need not include a range unit.

The normal output of tracking radar **10** is derived from information indicating the elevation and azimuth errors and the range to the target as indicated by the error signals received by receiver **102** and translated into position data appropriate for transmission to the computer in the range unit forming a part of the receiver and in servo unit **106** which derives the azimuth and elevation signals while orienting the antenna to reduce the error signals to zero. This servo unit may be considered to be a typical unit and is assumed for the present purposes that the azimuth and elevation error signals and the range signals are converted to electrical quantities corresponding to the azimuth range and elevation for individual transmission over a connector **20** to a predictor **22.** The form in which the target position data are determined is not significant since the means for converting data in one coordinate system to another system are well known in the computer art.

Target radar **10** produces a second set of output quantities for application to transmission link **108** which quantities are of the same nature as those applied to transmission link **20** and are representative of azimuth and elevation data. In this instance, however, they are derived from receiver **104** tuned to the frequency f_2 and converted in data unit **110.** It should by noted that the quantities obtained from data unit **110** are employed only for application to transmission link **108** and are not employed in the automatic tracking circuitry of target tracking radar **10.**

The missile tracking device **12** may be similar to target tracking device **10** and may in the same way produce output quantities proportional to the slant range, the elevation, and the azimuth of the missile as measured at the location of the missile tracking device. As shown in FIG. **1,** however, certain advantageous modifications have been made in the missile tracking device to improve the performance thereof. Basically these modifications involve recognition of the fact that the antiaircraft missile presents an extremely difficult target for a tracking radar. Accordingly it has been found desirable to employ a so-called radar beacon system rather than a conventional radar. For this purpose pulses are radiated from a transmitter **24** at a radio frequency f_1. The missile as will be explained in greater detail hereinafter carries a responder which is responsive to pulses of frequencies f_1 and radiated pulses of frequencies f_2. These pulses are picked up by antenna **25** and directed to a receiver **26** responsive to that radio frequency. The receiver **26** operates in a manner identical to that of target tracking radar **10** to provide the required output quantities as to azimuth and elevation for transmission over a connector **28** by way of a

transfer switch **112** operated by an actuator **114** and parallax correction unit **31** to a second predictor **30.** The output derived from the range unit of receiver **26** and representative of the range to the missile is applied directly to parallax correction unit **31** by way of connector **29.**

Normally and during all phases of an engagement other than the end game (the final increments of the engagement), transfer switch **112** remains in the position shown in FIG. **1** whereby the output quantities from missile tracking radar **12** are applied after correction for parallax to predictor **30** of computer **14.**

Radar beacon systems of the type contemplated for use in the missile tracking system are well known in the art and are discussed in detail in "Radar Beacons" by Roberts, Vol. 3 of "The Radiation Laboratory Series, McGraw-Hill, 1947." Modification of the SCR-584 radar referred to above as illustrative of the ground based missile tracking device, for this type of performance may easily be accomplished merely by tuning of the receiver to frequency f_2 rather than f_1. The missile borne equipment will be considered hereinafter.

As assumed above the quantities applied to predictor **22** indicate the present position of target **18** in spherical coordinates with respect to the location of the target tracking radar while those applied to predictor **30** represent similar information as to the position of the missile with reference to the location of the missile tracking radar. For ease in computation it is considered desirable to convert this information into rectangular coordinates with the origin at the location of the target tracking radar. Such coordinate conversion is well known in the art and may be accomplished as described, for example, in U.S. Pat. No. 2,408,081 to Lovell et al. which issued, Sept. 24, 1946. Conveniently each predictor **22** and **30** includes a coordinate converter acting to convert input quantities to rectangular coordinates (X, Y and H where X and Y are orthogonal axes in the horizontal ground plane and H is the vertical distance from the XY plane) with origins at the locations of the respective tracking radars. The necessary offset or parallax corrections referred to above and required to convert the data as to missile position to the coordinate system having its origin at the location of the target tracking radar may be set in manually in unit **31** associated with predictor **30** as potentials of suitable polarity along the three rectangular coordinates. These corrections are constants and once determined with adequate precision at the time at which the two tracking radars are emplaced, need not be changed unless the emplacement of the guidance equipment is changed. As pointed out above, however, the present invention permits substantial relaxation of the degree of precision required in these corrections. The errors in performance resulting from parallax are not of great importance in the early phases of an engagement. In the final phase control is switched according to the invention to eliminate the parallax correction problem in its entirety.

Computer **14** which includes predictors **22** and **30** acts on the basis of an assumed time of flight for the missile to reach a point of interception with the target. Using this time of flight the future positions of the target and missile at the predicted time of interception are computed independently. These positions are compared coordinate by coordinate to find the predicted position error at the predicted time of interception.

The corrections in either or both the time of flight assumed at the outset and the course of the missile required to insure interception may be determined from this information. Depending upon the nature of the missile either or both of these quantities may be altered to eliminate the position error by the predicted time of interception. This general philosophy of computation is similar in certain respects to that employed in antiaircraft gun direction systems of the type disclosed in the patent referred to above. In the computer herein disclosed, however, many of the operations are duplicated to provide information not only as to the target but also as to the missile since in the present case some measure of control remains after the missile is fired.

Assuming a time of flight, predictors **22** and **30** determine the future positions of both missile and target at the predicted time of intercept (T=0 where T is the time until interception). In each predictor the present position data is differentiated to obtain velocity and this velocity is multiplied by the time of flight to obtain future position. These operations are carried out in each instance in terms of components along the orthogonal X, Y and H coordinates which are ground coordinates with the origin at the location of the target tracking radar as indicated in FIG. 3 of the drawing.

As in the reference patent each predictor **22** and **30** provides three coordinate output data representing the predicted position of the target or the missile as the case may be when the predicted time of intercept occurs. These quantities are identified in FIG. **1** as X_T, Y_T and H_T for the target and X_M, Y_M and H_M for the missile.

These quantities are applied to a comparator **32** in which are subtracted coordinate by coordinate to obtain predicted position error quantities. The error outputs shown at the output of comparator **32** are E_H showing the position error in the H direction, and E_X and E_Y showing the position error in the X and Y directions, respectively.

A better understanding of the significance of these quantities may be obtained by reference to the diagram of FIG. **3.** Here the present heading of the missile is represented by the arrow labeled n_M and that of the target by the arrow n_t. If it is assumed that at the predicted time of intercept (T=0) the missile will have reached a position a specified *a* position specified with respect to the X, Y and H axes by the quantities X_M, Y_M and H_M referred to above and the target a position b similarly specified by the quantities X_T, Y_T and H_T. The total position error at T=0 for these assumptions is measured by the vector E, the components of which E_X, E_Y and E_H in the X, Y and H directions respectively are as shown in FIG. 3. It is apparent that these quantities are measured with reference to a set of coordinates fixed with respect to the target tracking radar and do not indicate directly what maneuvers must be performed by the missile to assure interception. It is necessary, therefore, to convert these error quantities into quantities measured with respect to a frame of reference traveling with the missile so that appropriate commands for missile guidance may be produced.

The method of providing the required frame of reference traveling with the missile and still identifiable at the location of the guidance equipment will become apparent with reference to the diagram of FIG. **2.** Here the missile **16** is shown as carrying a so-called free-free gyroscope **34,** the rotor of which is suspended in a conventional gimbal system. The outer gimbal **36** is journalled for rotation about the longitudinal axis of the missile while the inner gimbal **38** is journalled in the outer gimbal for rotation about an axis normal to the longitudinal axis of the missile. The gyroscope rotor is in turn journalled in the inner gimbal and spins about an axis normal to the inner gimbal axis. This third axis is hereinafter referred to as the gyro spin axis. In accordance with well understood principles the gyroscope acts to maintain the gyro spin axis G_A at a fixed orientation in space regardless of the maneuvers of the missile in which the gyroscope is mounted.

Conveniently, the gyro spin axis is initially oriented in the XY (horizontal) plane and, if possible, normal to the plane of the initial trajectory to the target. This axis and the longitudinal axis of the missile define a reference plane attached to the missile and identifiable at all times at the location of the guidance equipment as will be pointed out below.

The initial orientation of the spin axis may be determined before the missile is launched and the heading of the missile at any time is determined as one of the necessary functions of predictor **30.** It will be recalled that the rates of change of each of the X, Y and H quantities representing the present position of the missile are determined in the prediction process. These components of the missile velocity may be combined to give a quantity proportional to the missile velocity in the direction of the missile flight path. This combination of velocity components is performed by missile heading resolver **40** which is a conventional coordinate resolution device of the type employed generally in fire control computers. It is noted that the frame of reference traveling with the missile is based upon the gyroscope spin axis and the longitudinal axis of the missile while the information available to the computer includes the orientation of the gyro spin axis and the missile velocity. It has been found that, because of the continuous control of the missile afforded by the command system of the invention, the missile velocity vector may be considered to have the same orientation as the longitudinal axis of the missile. Any error so introduced is within the range of correction of the command system. It will be understood, however, that if sufficient information is available as to the aerodynamic performance additional computation equipment may be provided to determine the orientation of the longitudinal axis of the missile from the available missile velocity information.

It now becomes necessary to steer the missile with respect to the frame of reference just considered. As shown in FIG. 2 the missile is provided with two sets of paired steering fins **40** and **42** respectively. Fins **40** are mounted on a shaft **44** normal to the longitudinal axis of the missile and fins **42** are mounted on a shaft **46** which is normal to both the longitudinal axis of the missile and the shaft **44.** Shafts **44** and **46** thus constitute a pair of steering axes which will be referred to as the yaw and pitch axes respectively and which control the orientation of the missile in two orthogonal planes. As a matter of convenience the plane normal to shaft **44** will be referred to as the yaw plane (which is the same as the reference plane considered above) and that normal to shaft **46** as the pitch plane (which includes the longitudinal axis of the missile and is normal to the reference plane). Fins **40** then constitute the yaw steering fins and fins **42** the pitch steering fins. These fins are positioned in response to steering orders transmitted

from computer **14** to control the course of the missile after launching.

It is apparent that the course of the missile can be properly controlled only if the steering axes represented by shafts **44** and **46** remain respectively normal to and in the plane of reference considered above and defined by the gyro spin axis and the longitudinal axis of the missile. This condition requires roll stabilization of the missile. For this purpose the missile is equipped with paired cruciform tail fins **48** and **50** and adjustable ailerons **52** are provided upon the trailing edges of at least one pair of tail fins (**48** in FIG. **2**). Conveniently gyroscope **34** is employed to control ailerons **52** in such a way as to roll stabilize the missile with respect to the reference plane.

The outer gimbal **36** of the gyroscope **34** is coupled to the movable arm of a potentiometer **54** through a shaft **56** which forms an extension of the outer gimbal axis. Potentiometer **54** comprises a source of error signal for a servo system including an amplifier **56,** a motor **58** and suitable linkage **60, 62** whereby opposite deflections of upper and lower ailerons **52** may be produced by motor **58.** Although these elements, together with the gyroscope **34** which constitutes the error detecting element, may be connected to form any of a large number of known kinds of servo system, it may be assumed for the purposes of the present description that a simple direct current servo system is employed.

Potentiometer **54** is provided with a center-tapped winding to which direct current potentials are applied from a source such as a battery (not shown to avoid undue complexity in the drawing). The circuit is so arranged that no output is produced when shaft **44** is normal to the reference plane. Whenever the potentiometer arm is moved from this normal (null) position an output is developed, the amplitude and polarity of which are indicative of the amount and direction of the roll of the missile from the desired position. After amplification this output may control motor **58** as in the usual direct-current servo system, causing deflection of the ailerons in the proper direction to return the missile to the desired orientation as indicated by the null output from potentiometer **54.**

It will be understood that as a result of such roll stabilization fins **40** are effective to produce steering forces in the yaw plane and the other pair of steering fins **42** act to produce steering forces in the pitch plane. Thus there is provided a set of orthogonal reference coordinates traveling with the missile and comprising the yaw axis y, the pitch axis p and the missile heading h_m. Further the orientation of this reference system in space is continuously determinable at the location of the ground guidance equipment.

It will be recognized that by the usual process of coordinate conversion the total position error E shown in FIG. **3** may be expressed in terms of components along the reference axes traveling with the missile. Such conversion may be accomplished in coordinate resolver **64,** FIG. **1** as outlined beginning page **279** of "Electronic Analog Computers" by Korn and Korn or in U.S. Pat. No. 2,658,674 to Darlington et al., Nov. 10, 1953 which resulted from an application filed Feb. 13, 1945 particularly in FIG. **38** and the specification beginning at column **92** thereof. This coordinate resolver accepts the three position error components E_H, E_X and E_Y shown in FIG. **3** and in addition accepts quantities from the output of missile heading resolver **40** indicating the

orientation of missile heading axis in space and quantities representing the position of the gyro spin axis G_a which may be set into the coordinate resolver as constants. The outputs of coordinate resolver **64** are E_y and E_p representing position errors in the yaw and pitch planes and measured along the pitch and yaw axes respectively and E_t representing a position error along the missile path. These components are shown in FIG. **3** with respect to the missile axes p, y and h_m, (drawn with an origin at point c, the present position of the missile.)

E_t, the predicted position error along the missile path is a measure of the adjustment which must be made in the time of flight (or the velocity) of the missile to cause interception of the target. If it be assumed that the velocity of the missile is not subject to external control once the missile is launched, this correction must be made by varying the time of flight originally assumed at the outset of the computation process and employed as one input to each of predictors **22** and **30.** This quantity is, therefore, applied to a time of flight servo mechanism **60** and controls the setting of input quantities to the two predictors possibly as a shaft rotation as in the predictors shown in U.S. Pat. No. 2,408,081, referred to above. The quantity controlling predictor **22** is applied directly thereto. However, the corresponding quantity for predictor **30** which is associated with the missile section of the computer is modified in accordance with the ballistic characteristics of the missile before application to predictor **30.** Such modifications are accomplished by apparatus **62** wherein appropriate changes are made in the value of time of flight. These changes are ordinarily accomplished by adding both fixed and variable components to that corresponding to the time of flight as shown for example in FIG. **8A** of U.S. Pat. No. 2,408,081 to which reference has been made above.

It will be understood from the above that the necessary functions for the continuous prediction process performed by the computer are provided by way of the time of flight servo mechanism and the target and missile tracking radars. The pitch and yaw error outputs E_y and E_p from coordinate resolver **58** are employed for the generation of steering orders for the missile. These quantities depend of course upon the time of flight fed back to predictors **22** and **30** as discussed above. As a matter of convenience in control of the missile it has been found desirable to convert these position orders into acceleration orders, i.e., the quantities representing the position errors measured along the yaw and pitch axes are converted into lateral accelerations in the pitch and yaw planes respectively such that the missile will be at the point of predicted interception at the predicted time of interception. For the generation of such orders the quantities E_y and E_p are applied respectively to dividers **70** and **72** in which each is divided twice by the time of flight produced as the output of unit **66.** The yaw and pitch orders appearing at the outputs of dividers **70** and **72** respectively are thus proportional to the accelerations required to cause the missile to reach the predicted point of interception at the predicted time of interception. These orders may be transmitted to the missile by any convenient means, for example, by a high frequency radio communication channel.

Alternatively and as shown in FIG. **1** the acceleration orders for the missile are transmitted by modulation of

the repetition rate of the missile tracking pulse transmitter. The necessary control quantities may be transmitted on a time division basis or any other convenient basis by the action of a modulator **74** associated with transmitter **24.** Various systems of signaling over the radar beam are described in Section 11.2 of "Radar Beacons," Vol. 3 of the "Radiation Laboratories Series". According to one such system the two control signals are transmitted as audio frequency signals frequency modulated upon the pulses from the track transmitter. Either one or both of the frequencies can thus be transmitted depending upon the steering orders required at a particular time, the modulating wave comprising either one or the sum of the audio frequencies.

Also transmitted to the missile and conveniently by interruption of all modulation upon the radar beam is the so-called burst order which at a time related to the predicted time of intercept causes the warhead of the missile to explode. Ordinarily this order is transmitted a few microseconds prior to the time when T=0.

The remaining equipment carried aboard the missile may now be considered. As has been stated above the missile carries a transponder responsive to pulser from the ground base missile tracking equipment. This transponder includes a receiver **68** tuned to frequency f_1 associated with antenna **70,** and a microwave pulse transmitter **72** which is triggered by the output of receiver **68** and which radiates pulses of frequency f_2 from antenna **74.** These pulses when received at the location of the guidance equipment permit tracking of the missile.

Radio receiver **68** also serves to receive the various orders transmitted from the guidance equipment and intended to control the steering fins of the missile and the bursting of the warhead at appropriate times. Depending upon the nature of the modulation employed to transmit these orders this portion of receiver **68** may include a frequency modulation demodulator, pulse position demodulators or decoders or a frequency division multiplex receiver wherein the various order channels are distinguished upon a frequency basis. In any event the receiver is designed with reference to the particular transmitter **24, FIG. 1,** employed in the guidance equipment and produces three output signals corresponding respectively to the pitch and yaw acceleration orders and the warhead burst order.

As shown in FIG. **2** each pair of missile steering fins is driven by an electric motor, in response to the appropriate orders occurring at the output of receiver **68.** Thus a motor **76** is geared to the shaft **44** upon which steering fins **40** are mounted and a motor **80** is geared to the corresponding shaft **46** upon which steering fins **42** are mounted. It will be recalled that the missile is to be made responsive to acceleration orders. Accordingly for each set of steering fins the appropriate order appearing at the output of radio receiver **68** is applied to an amplifier to which is also applied an output of an accelerometer. These two quantities are applied in opposition and the motor is driven from the output of the amplifier until the accelerometer indicates that the desired angular acceleration has been introduced. When such a condition occurs the output of the amplifier is reduced to zero and the motor stops. If the angular acceleration increases, the output of the accelerometer exceeds the order output of the receiver and the motor is driven in the appropriate direction to return the acceleration to the required value. The yaw steering fins **40** are thus controlled by the output of the comparison amplifier **84** to which is applied the output of an accelerometer **86** oriented in the missile to indicate accelerations about the yaw axis. Similarly the pitch steering fins **42** are controlled by a comparison amplifier **88** to which is applied the pitch order output of the receiver and the output of an accelerometer **90** oriented in the missile to detect accelerations about the pitch axis.

The remaining equipment in the missile includes a warhead **92** furnished with an appropriate detonator which may be actuated by an electric impulse known as the burst order received from the third output of receiver **68** and applied to the warhead over lead **94.**

In the operation of the missile system as thus far described the missile is launched and guided toward interception with the target in the same manner as that disclosed in the copending application, Ser. No. 449,396 referred to above. However, and in accordance with the present invention the missile tracking function is transferred from the missile tracking radar **12** to the target tracking radar which is modified as described above so that during the final phases of an engagement, referred to above in some instances as the end game, both target and missile are tracked in elevation and azimuth by the same radar, in this instance target tracking radar **10.** Under these circumstances those data as to position of both target and missile which are most sensitive to error are referred to the same reference system and such matters as parallax between the two tracking radars and the accurate bore-sighting of both as required to insure appropriate corrections are substantially eliminated. Conveniently the time in which transfer of control from the missile tracking radar to the target tracking radar is effected is determined by the reduction of the angular separation of the tracking beams of target tracking radar **10** and missile tracking radar **12** to a predetermined small amount. Although this criteria for switching is considered the most desirable because of the fact that in the normal engagement the missile and target tend to be in approximate alignment in the final phases of the engagement, other criteria for switching may well be employed. For example, switching may be effected when the time to go to predicted interception has been reduced to a predetermined value. In any event, switching should not occur until the missile has approached sufficiently near to the target to be illuminated by the beam of the target tracking radar.

In any event information as to the reduction of the switching criteria to a predetermined value is transmitted over leads **116** and **118** from target tracking radar **10** and missile tracking radar **12,** respectively, to a control circuit **120.** When the predetermined criteria has been realized control circuit **120** becomes effective to operate actuator **114** switching the input of predictor **30** from the output of parallax unit **31** associated with lead **38** from missile tracking radar **10** to lead **108** from receiver **104** of the target tracking radar. It will be noted that this transfer eliminates the parallax correction unit **31** from the elevation and aximuth inputs to predictor **30** since such correction is no longer required. From this time onwards during the engagement both target and missile are illuminated by the beam from target tracking radar **10** and the automatic tracking equipment of this radar maintains it in such orientation as to keep both target and missile within the beam.

The beacon signals from missile **16** may thus be received by receiver **104** associated with the target tracking radar and from these received signals may be derived error quantities representative of the failure of the target tracking antenna to track the missile exactly in elevation and azimuth. In the conventional tracking radar, these error signals are employed as inputs to servo devices arranged to orient the antenna and adjust the range unit in such a way as to reduce the errors in tracking effectively to zero. Here, however, antenna orientation and range unit adjustment are and remain under control of the target tracking radar and are effected in response to the error signals from receiver **104.** The error signals ΔA_m, and ΔE_m, representing the azimuth and elevation errors in the tracking of the missile by the target tracking radar are therefore applied to an adder **110.** This device is of conventional type and includes three channels in which ΔA_m and ΔE_m are algebraically added to A_T, and E_T respectively as derived from servo unit **106.** The output of adder **110** as applied to transmitting channel **108** includes separate quantities representing A_m and E_m of the missile position data as required by predictor **30** of the computer. Missile range data for application to predictor **30** continues to be derived from the range unit of missile tracking radar **12** and is applied by way of parallax correction unit **31** as noted previously. These quantities representing angular position are applied to predictor **30** in preference to those normally supplied by missile tracking radar **12** and the computer treats them in the same manner as though they were derived from missile tracking radar **12** and the remainder of the system operates exactly as previously described. The single reference for both missile and target position data is thus achieved for the azimuth and elevation quantities and the need for accurate parallax and bore-sight adjustments is eased during that phase of the engagement for which these quantities become of the greatest importance.

The control system by means of which the approach of angular separation of the two tracking beams to within the predetermined small quantity, for example 1° in both elevation and azimuth, may be detected will now be described with reference to FIG. **4** of the drawings. Here the antenna platforms **122** and **124** of target and missile tracking radars respectively are shown schematically. These units may include any combination of synchros, converters, motors, etc., as required according to well known principles, to provide an output which is the differential between two inputs. The exact nature of the units will be dependent upon the nature of the inputs and outputs which may be electrical quantities or mechanical shaft rotations as indicated in FIG. **4.** Each of these platforms will be understood to provide for rotation of the antenna proper in elevation and azimuth. In the control circuitry now to be considered the azimuth shaft of missile tracking radar platform **124** is connected to a synchro transmitter **126** while the azimuth shaft is connected to a similar transmitter **128.** In a similar manner the elevation shaft of target tracking radar platform **122** is connected as one input to a differential synchro unit **130** and the azimuth shaft is connected as one input to a differential synchro unit **132.** For ease of illustration, the various components such as synchros are shown adjacent to the antenna platforms to which they are linked. It will be understood that with the exception of antenna platforms **122** and **124,** all of the elements shown in FIG. **4** are a part of the control circuit **120** shown schematically in FIG. **1.** The electrical output of elevation transmitter **126** is applied as the second input as the differential synchro **130** and the electrical output of azimuth **128** is applied as the second input to differential synchro **132.** The output shaft of differential synchro **130** is mechanically connected to a switch **134** and the corresponding shaft of differential synchro **132** is connected to a switch **136.** Switches **132** and **136** are simple single pole switches through which may be completed a series circuit including a source of potential such as a battery **138** and actuator **114** of FIG. **1.**

The mechanical output of each of differential synchros **130** and **132** constitutes a measure of the angular separation about the associated axes of radar platforms **122** and **124** thus switch **134** is closed whenever the two elevation shafts approach within 1° of angular separation and switch **136** is closed whenever the azimuth shafts approach within the same limit. When both switches are closed the requirement for switching of the control from the missile tracking radar to the target tracking radar is made and actuator **114** closes transfer switch **112** and the required transfer of control is effected.

What is claimed is:

1. In an antiaircraft system, target tracking means for continuously establishing the position of a target aircraft in space, missile tracking means for similarly establishing the position of a missile, computing means responsive to position information from both said target and missile tracking means to produce control signals for said missile to insure interception of the target thereby and means for substituting the target tracking means for said missile tracking means as a source of missile position information for said computing means during the final phases of an engagement.

2. In an antiaircraft system a tracking radar for establishing the position of a target aircraft in space, a second tracking radar for similarly establishing the position of a missile launched against said target aircraft, computing means responsive to position information from both of said radars to produce control signals for said missile to insure interception of the target aircraft thereby, means for detecting the approach of the missile to within a predetermined separation from said target aircraft and means responsive to said detecting means for substituting the target tracking radar for said missile tracking radar as a source of missile position information.

3. In an antiaircraft system target tracking means for continuously establishing the azimuth, elevation and range to a target aircraft, missile tracking means for similarly establishing the position of a missile, computing means responsive to the position information from both target and missile tracking means to control the path of said missile to insure interception of the target thereby and means for substituting the target tracking means for said missile tracking means as the source of missile azimuth and elevation information during the final phases of an engagement.

4. In an antiaircraft system a missile tracking radar operating at a first frequency, a target tracking radar comprising a transmitter operated at a second frequency and receiving means capable of separate response to echo signals of both said first and second frequencies, computing means normally responsive to tar-

get and missile position information derived from said first and second radars respectively to control the path of said missile to insure interception of the target thereby and means operative during the final phase of an engagement to substitute as a source of missile position information for said computer the output of the target tracking receiving means produced in response to echoes of said second frequency in place of the output of the missile tracking radar.

5. In an antiaircraft system a target tracking radar for continuously establishing the position of a target aircraft in space, a missile tracking radar for similarly establishing the position of a missile launched against said target aircraft, computing means responsive to position information from both said target and missile tracking radars to produce control signals for said missile to insure interception of the target aircraft thereby, means for determining the angular separation in both elevation and azimuth of the tracking beams of said radars and means operative when both of said angular separations are reduced below predetermined values for substituting the target tracking radar for said missile tracking radar as a source of missile position information for application to said computing means.

6. Apparatus for controlling a guided missile relative to a target comprising missile tracking radar apparatus, target tracking radar apparatus and computer apparatus connected with said respective missile tracking and target tracking radar apparatus, said target tracking radar apparatus comprising means independently receiving radio signals from said missile and said target for simultaneously supplying said computer apparatus with information signals in accordance with the angular position of said missile and the range and angular position of said target.

7. In an antiaircraft system target tracking means for continuously establishing the position of a target aircraft in space, missile tracking means independent thereof for similarly establishing the position of a missile launched against said target aircraft, a computer, means for applying the output of said target tracking means to said computer, means for applying the output of said missile tracking means to said computer after correction for parallax between said missile and target tracking means, said computer being arranged to produce orders for said missile to insure interception of the target aircraft by said missile and means operative when the target aircraft and missile approach one another to within a predetermined separation for substituting the output of said target tracking means as a source of missile position information in place of the missile tracking means and the means for correcting for parallax as to the information for which such substitution is made.

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